

Reprint & Copyright © by
Aerospace Medical Association, Washington, DC

Patterns of Skin Temperature and Surface Heat Flow in Man During and After Cold Water Immersion

L. D. REED, Ph.D., S. D. LIVINGSTONE, Ph.D., and
R. E. LIMMER

*Defence and Civil Institute of Environmental Medicine,
Downsview, Ontario, Canada M3M 3B9*

REED, L. D., S. D. LIVINGSTONE and R. E. LIMMER. *Patterns of skin temperature and surface heat flow in man during and after cold water immersion*. *Aviat. Space Environ. Med.* 55(1):19-23; 1984.

The region of the lateral thorax, previously identified as an area of high heat transfer during cold water immersion, was investigated using heat flow discs and thermography to determine values of local heat flow and surface temperature before, during, and after immersion. The effect of different positions of the arms on local heat flow from the torso was also investigated. No large site-to-site variation in local heat flow was detected for immersion in water temperatures in the range 18.7-24°C. When the arms were positioned close to the torso, there was a marked decrease in local heat flow and an increase in local surface temperatures. Thermographic examinations revealed local regions of elevated temperature after the arms were briefly held against the body in the postimmersion stage. In this circumstance, erroneous results can follow from the assumption that an elevated surface temperature always constitutes a signal of increased regional heat flow.

IN A STUDY BY Hayward and co-workers (3), an infrared thermographic system was used to investigate the distribution of surface temperature in nearly nude subjects after cold water immersion for 15 min at 7.5°C. The areas of high temperature were assumed to be areas of high relative heat loss and Hayward *et al.* concluded that, for subjects who remained motionless during immersion, the areas of major heat loss were the lateral thorax, upper chest, upper back, and groin. The authors recognized that skin temperatures would be higher and extend over a greater range after immersion than during immersion due to the "clamping" effect of cold water on bare skin. They suggested a closer study of the regional differences in heat transfer rates using heat flow discs.

L. D. Reed and S. D. Livingstone are now with the Defence Research Establishment Ottawa, Department of National Defence, Ottawa, Ont., Canada K1A 0Z4.

84-P-37

This suggestion was particularly important because some of the specific high-temperature areas identified in the thermographic study may have been the result of situations in which adjacent parts of the body limited the heat loss of one another, thereby leading to high interfacial temperatures (as in finger-finger, arm-chest, and leg-leg contacts). Jones and Xenofos (5) have published a study of such influences by body contours on surface temperature distributions. In addition, Boutelier (1) attributed a decrease in the rate of heat loss to the instinctive reduction of a person's surface area of exchange by a change in posture upon immersion.

A knowledge of regional variations in heat transfer rates has important applications both in designing the distribution of insulation in personal flotation devices and in selecting sites for the application of external heat to hypothermic patients. The present study was designed to investigate variations in regional heat transfer from the torso during immersion (using heat flow discs), and immediately after immersion (using a thermographic system in addition to the heat flow discs). By using higher water temperatures (18.7-24.0°C) than those used by Hayward *et al.* (3), it was possible to study the details of body temperature changes as a function of posture and time, under conditions of relative safety for the subjects.

METHODS

Five male volunteers gave their informed consent to participate in a series of studies which involved their immersion, while dressed only in bathing trunks, in cool water for up to 60 min. Age, height, mass, and skinfold thickness of the subjects are shown in Table I. Prior to the immersion, an array of thermoelectric heat flow discs (Thermometrics Models HA 12-18-10-P(C) and HA 12-18-5-0) were attached using surgical tape (3M Blendederm). Each heat flow disc included

COLD WATER IMMERSION—REED ET AL.

TABLE 1. ANTHROPOMETRIC CHARACTERISTICS OF THE SUBJECTS.

Subject	Age (years)	Height (cm)	Mass (kg)	Skinfold thickness (mm)		
				Tri-cope	Sub-scapular	Supra-iliac
A	32	181.0	75.2	11.2	10.8	12.0
B	43	177.0	85.8	13.0	24.1	31.8
C	53	175.0	80.1	11.6	21.5	25.3
D	30	170.5	78.7	11.5	23.3	40.1
E	41	188.5	89.4	8.0	13.5	19.6

a thermistor, which allowed measuring skin temperature at the site of each heat flow measurement. The sites for the discs were chosen to explore the high heat flow regions identified by Hayward *et al.* (3). The configuration used is shown in Fig. 1. An automatic data acquisition system measured and stored the values of heat flow and skin temperature every minute at each site.

The need for calibration of heat flow sensors has been stressed by such field researchers as Nuckols and Piantadosi (6); hence, the sensitivity of the heat flow sensors, relative to the one chosen as a standard, were determined by measuring the electrical signals produced by the standard and each other sensor, in turn, when they were symmetrically



Fig. 1. Configuration of sites at which heat flow and temperature measurements were taken.

attached to the ends of an insulated heated copper cylinder located inside a temperature-controlled chamber. For the 20 sensors which were used in the various immersions, a linear regression analysis yielded the following relationship between the measured relative sensitivity, y , and the relative sensitivity cited for the discs when they were new, x : $y = -1.04 + 1.86x$; $r^2 = 0.80$. All heat flow calculations were then based on these calibrations.

An infrared thermographic system (AGA Model 680) was also used to study skin temperature distribution before and after immersion. The system was equipped with a patented electronic areameter (7,8) to measure the surface area associated with each of 10 adjacent narrow-temperature intervals. Data from the areameter could be used, with the calibration data of the thermography system, to determine mean surface temperatures.

After initial measurements were completed, the subjects, clothed only in boxer swim trunks, descended a ladder to stand neck deep on a support in gently stirred water in an immersion tank 2.5 m long, 2.4 m wide, and 3.0 m deep. Two basic positions were employed. The subjects either stood erect with the arms at the sides and legs together, or with legs slightly apart and arms outstretched horizontally. At the end of the immersion period, the subjects ascended the ladder and were gently patted with towels to remove water drops.

Postimmersion thermography, which began within a minute of the subject leaving the water, involved areameter measurements, photographic recording of the thermograms taken in a variety of standing poses, and a thermographic

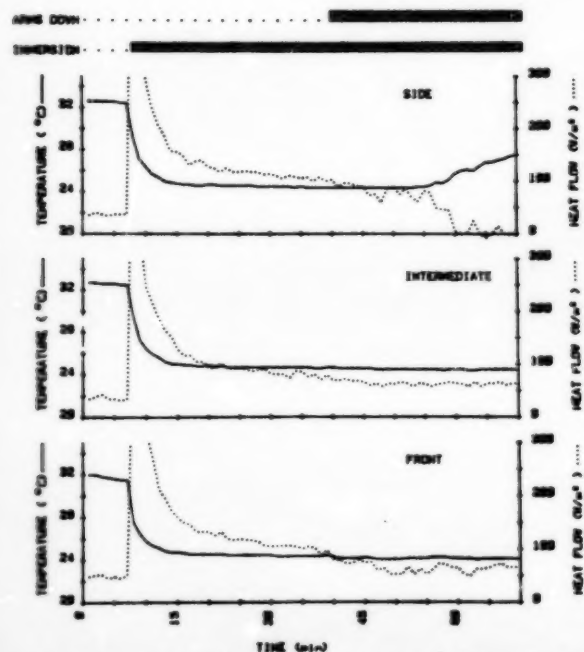


Fig. 2. Graphs showing temperatures and heat flow from the side, intermediate, and front sensors at the level of the xiphoid process. Temperature is indicated by the solid line and heat flow by the dotted line. The time of immersion and periods in which the arms are down are indicated above the plots. Note the effect of lowering the arms on the temperature and heat flow at the site on the side. (Subject B; water temperature 24°C.)

COLD WATER IMMERSION—REED ET AL.

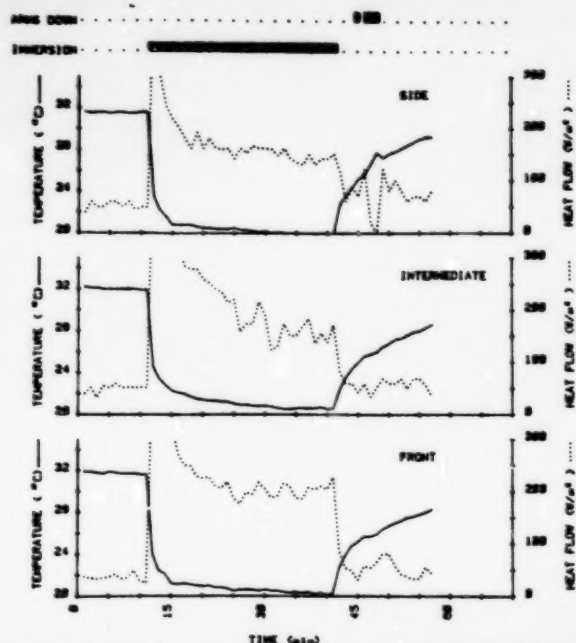


Fig. 3. Graphs showing temperature and heat flow from the side, intermediate, and front sensors at the level of the xiphoid process before, during, and after immersion. Temperature is indicated by the solid line and heat flow by the dotted line. The time of immersion and periods in which the arms are down are indicated above the plots. (Subject A; water temperature 18.7°C.)

assessment of skin temperature distributions observed while the subjects rotated slowly in front of the camera.

RESULTS

The temporal variations of heat flow and skin temperature shown in Fig. 2 for different sites on the torso are typical of results obtained in the series of trials. These measurements were taken at the intermediate sensor height shown in Fig. 1. For each site, the value of the skin temperature was relatively constant before immersion and then fell during the immersion phase to a value which approximated the 24°C temperature of the water. Heat flow from the three sites had relatively constant values of approximately $50 \text{ W} \cdot \text{m}^{-2}$ prior to immersion; rose markedly at the instant the subjects entered the water; and then decreased over a period of 15–20 min to about $50\text{--}100 \text{ W} \cdot \text{m}^{-2}$.

When the immersed subjects' arms were lowered, Fig. 2 shows that the temperature of the side site rose and that the heat flow at that site decreased only when the arm was in contact with the side sensor.

Fig. 3 relates to a trial in which the arms were outstretched throughout immersion in 18.7°C water and then were held against the torso for brief periods after immersion. The general features of the variations of torso skin temperatures and heat flow values resemble those at corresponding phases in Fig. 2. The major differences are that the skin temperatures fell on immersion to lower values in the colder water, and the heat flow stayed at higher values following a peak at the start of immersion. After the subject left the water, the arms were lowered for 37 s and then raised to allow a thermo-

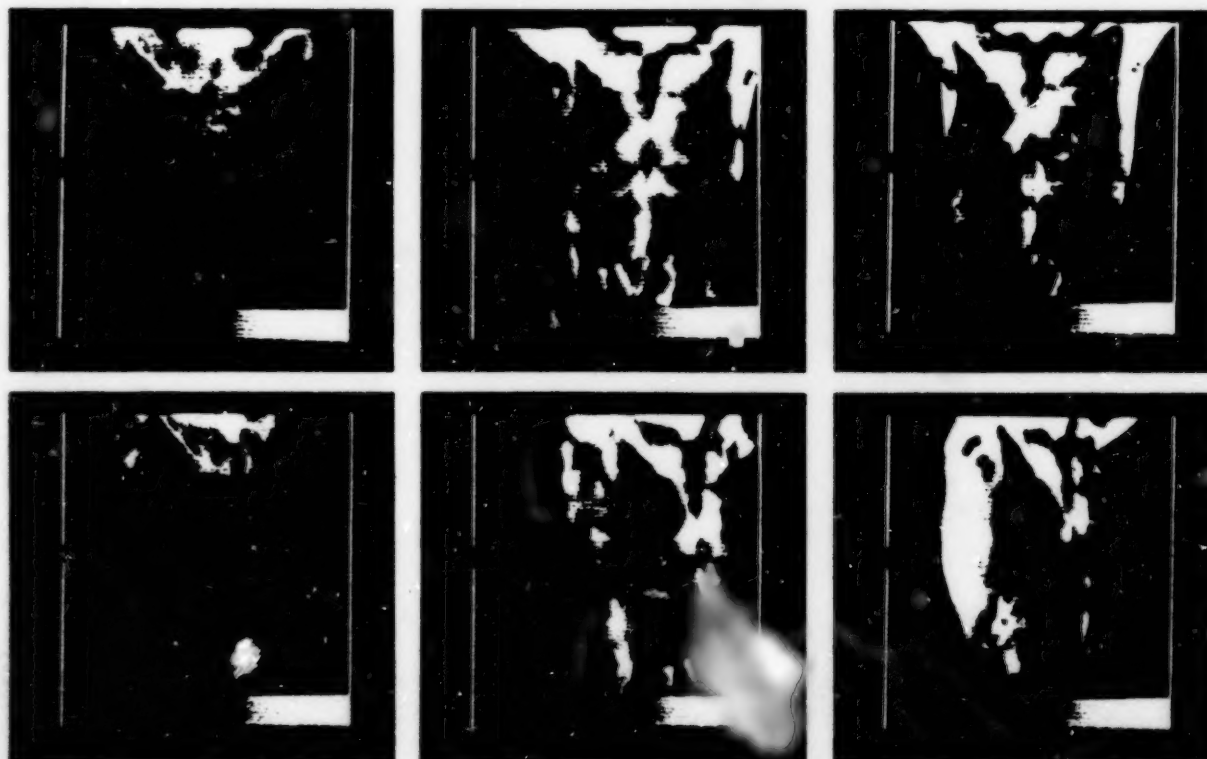


Fig. 4. Six torso thermograms showing the pattern of temperature (left to right) before immersion, after immersion, and immediately after the arms had been lowered for 145 s. The front view of each pair is at the top and the right oblique view is at the bottom. White indicates higher temperatures than the dark areas.

COLD WATER IMMERSION—REED ET AL.

graphic examination of the lateral thorax; the arms were then lowered for 145 s and raised for further thermographic examination of the lateral thorax. The periods during which the arms were lowered are marked in Fig. 3. The temperature of the side sensor increased and the value of the heat flow decreased during the longer period when the arms were lowered.

Six torso thermograms of this trial are shown as front and right-oblique pairs in Fig. 4. Each thermogram pair portrays some point-to-point variation in skin temperature, but no marked differences of the type described by Hayward *et al.* (3) were observed. The pronounced white area on the lateral thorax, which was evident after the arms had been lowered for 145 s (third thermogram pair), was not seen to any marked extent either immediately after leaving the water or after lowering the arms for a period of only 37 s. Fig. 5 and 6 show aspects of the site-to-site variations of torso heat flow and of skin temperature experienced by Subject A before, during, and after immersion in water at a temperature of 18.7°C.

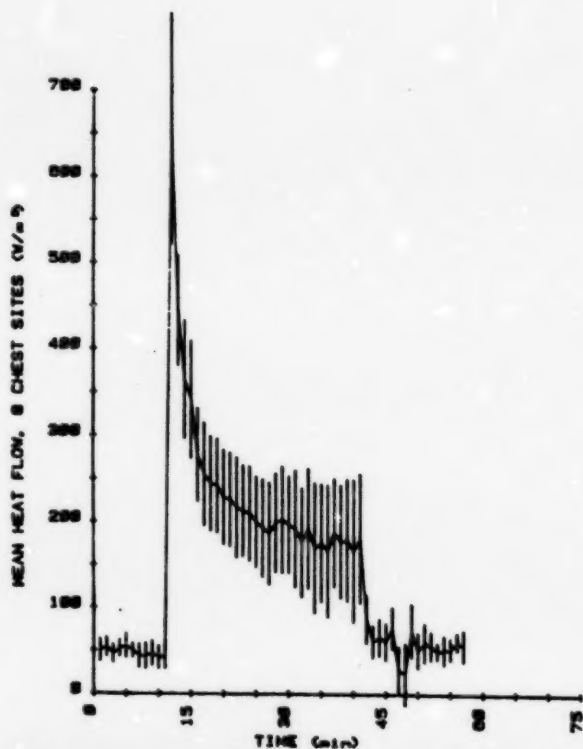


Fig. 5. Heat flow (unweighted mean for 8 chest sites) indicating mean $\pm$ S.D. before immersion, while in the water, and during recovery. (Subject A; water temperature 18.7°C.) Time of immersion is shown by the broad horizontal bar.

DISCUSSION

No well-defined torso heat loss areas were observed with the methods of the present study. The surface temperatures and heat losses sensed by heat flow discs on the torso varied relatively little from site to site, both during and after immersion; postimmersion areameter determinations of the mean temperature of the entire front of the torso differed less

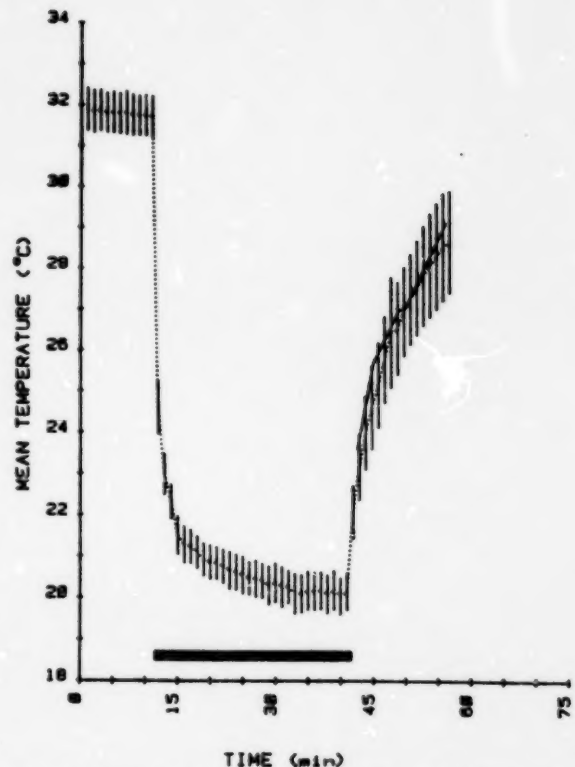


Fig. 6. Mean $\pm$ S.D. of temperature at 8 chest sites before, during and after immersion. The solid curve, which begins at the end of the immersion period, indicates the mean skin temperature measured by the thermographic system and areameter. (Subject A; water temperature 18.7°C.)

than 1 S.D. from the mean sensor temperatures. However, heat flow was reduced locally to zero in several immersions by lowering the arms to "protect" the sides of the torso. Local areas of relatively high torso temperature were only observed in thermographic examinations if the arms had previously been held against the body. For example, the procedure adopted to produce the third thermogram pair of Fig. 4 produced a markedly warm area on the lateral thorax.

In the study conducted by Hayward *et al.* (3), the immersions involved colder water for shorter periods (7.5°C for 15 min) compared with the present study. Boutelier (2) has investigated the variation of the thermal conductance of the body as a function of water temperature and has shown that conductance values decrease to a relatively constant value when the water temperature is reduced to less than 30°C. He has deduced from his measurements that complete vasoconstriction during water immersion occurs in the relatively narrow range of 33.5–30.0°C. It is unlikely, therefore, that marked differences in the relative importance of regional torso heat flow would develop at the lower immersion temperatures used by Hayward *et al.* unless some previously unreported cold-induced vasodilation phenomenon were to be particularly important at localized sites on the torso.

The results of our study support the practice of huddling and the use of "Heat Escape Lessening Postures (HELP)" (4) during accidental cold water immersion. Parts of the body can be effectively protected during cold water immersion by

COLD WATER IMMERSION—REED ET AL.

adjacent bodies or limbs, as seen in the "arms down" position (Fig. 2) in immersions of the present study.

Geometrical factors should similarly be considered in assessing thermograms of the groin area. The elevated "crease" temperatures observed by Hayward *et al.* (3) do not necessarily imply that the region is one of increased heat flow. In addition, the thermograms of that study will have been affected by the bathing suit each subject wore during immersion. The suit was removed prior to the thermographic examination.

Because the groin is so difficult to study by either of the methods used in the present study, it is suggested that the important question of whether or not the groin is a major area of heat loss be resolved by other means. Selective insulation of different parts of the body during whole-body water calorimetry may yield results more directly.

CONCLUSIONS

It is concluded that point-to-point differences in heat flow from an unprotected torso during cold water immersion at the temperatures used (18.7–24°C) are less marked than had previously been deduced from thermographic observations. However, it has been shown that individuals can assume positions in which adjacent body parts protect one another from rapid loss of heat.

Thermograms taken to study variations in heat loss from surfaces must be carefully interpreted, especially when the proximity of adjacent parts of the body produces relatively

low heat flow rates accompanied by relatively high interfacial (or "crease") temperatures.

ACKNOWLEDGMENT

The participation of all who volunteered for this experiment is greatly appreciated. The assistance of Messrs. L. Allin, C. Bowen, and R. Nolan is also greatly acknowledged.

REFERENCES

1. Boutelier, C. Survival and protection of aircrew in the event of accidental immersion in cold water. NATO Advisory Group for Aerospace Research and Development, AGARDograph No. 211, p. 24, 1979.
2. Boutelier, C. Survival and protection of aircrew in the event of accidental immersion in cold water. NATO Advisory Group for Aerospace Research and Development, AGARDograph No. 211, p. 36, 1979.
3. Hayward, J. S., M. Collis, and J. Eckerson. Thermographic evaluation of relative heat loss areas of man during cold water immersion. *Aerospace Med.* 44:708–711; 1973.
4. Hayward, J., J. Eckerson, and M. L. Collis. Effect of behavioural variables on cooling rate of man in cold water. *J. Appl. Physiol.* 38:1073–1077; 1975.
5. Jones, C. H., and S. S. Xenofos. The influence of body contours on surface temperature distribution. *Acta Thermographica* 4:113–117; 1979.
6. Nuckols, M. L., and C. A. Piantadosi. Calibration and characterization of heat flow transducers for use in hyperbaric helium. *Undersea Biomed. Res.* 1:249–256; 1980.
7. Reed, L. D., M. R. Howat, and J. E. Ulrichsen. Thermographic Area-meter. U.S. Patent 4218707, 19 Aug., 1980.
8. Reed, L. D., M. R. Howat, and J. E. Ulrichsen. Thermographic Area-meter. Canadian Patent 278,419, 4 Nov., 1980.

POOR

QUALITY

ORIGINAL